AN EVALUATION OF CLIMATIC, MORPHOEDAPHIC, AND EFFORT DATA AS PREDICTORS OF YIELDS FROM ONTARIO SPORT FISHERIES

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ABSTRACT

Schlesinger, David A. and Alen M. McCombie. 1983. An evaluation of climatic, morphoedaphic, and effort data as predictors of yields from Ontario sport fisheries. Ont. Fish. Tech. Rep. Ser. No. 10: iii & 14p.

The purpose of this study was to determine the relative usefulness of the morphoedaphic index (MEI = total dissolved solids/mean depth), angling effort (E), lake surface area (A), and long-term mean annual air temperature in the lake vicinity (TEMP) for predicting sport fishing yields (Y) for a set of 85 Ontario lakes, 6 Minnesota lakes, and Lake Tahoe, California. Angling effort proved to be the best single independent variable, producing the equation:

$$\log_{10} Y = 0.668\ (\log_{10} E) - 0.507$$

with $r^2 = 0.611$

where Y is stated in kg/ha/yr and E in angler-hours/ha/yr. A multiple regression equation of the form:

$$\log_{10} Y = 0.564(\log_{10} E) + 0.548(\log_{10} \text{MEI}) - 0.181(\log_{10} \text{MEI})^2 - 0.614$$

with $r^2 = 0.748$

where the MEI is given in mg/L/m, considerably improved the correlation. In contrast, lake surface area and TEMP were of questionable value as independent variables, as indicated by a step-wise regression analysis.

Keywords: sport fishing yields, prediction, effort, morphoedaphic index, temperature, surface area, lakes

AN EVALUATION OF CLIMATIC, MORPHOEDAPHIC, AND EFFORT DATA AS PREDICTORS OF YIELDS FROM ONTARIO SPORT FISHERIES

INTRODUCTION

Management plans for sport fisheries should be designed to provide the best possible angling opportunities for the public. At the same time, self-sustaining game fish populations must be protected by insuring a continual reproductive surplus of mature individuals. To achieve these goals, it is important to have a reliable method for estimating the maximum sustainable yield (MSY) for a fish community or for individual species in the community. It is also necessary to distinguish the relative importance of physical and chemical characteristics of a lake (such as total dissolved solids and mean depth), angling effort, and climate in determining what the yields can be.

Ryder (1965) dealt with two of these variables when he divided total dissolved solids (TDS) by mean depth ($\bar{z}$) to create the morphoedaphic index (MEI), and he found a positive relationship between the MEI and commercial fishing yields from 23 lakes in Canada and the United States. The relationship is described by the equation:

$$\log_{10} Y = 0.45(\log_{10} MEI) + 0.146 \qquad \text{Eq.(1)}$$

where Y is the total yield of all fish species in kg/ha/yr, and the MEI is in mg/L/m. Since Ryder's data set was comprised of lakes which had withstood moderate to heavy fishing pressure over an extensive period, Ryder considered that yields calculated from this formula were estimates of the "potential" yield of the lakes. Hence, the equation has been used to estimate maximum sustainable yields from sport and commercial fisheries in many Ontario lakes.

Subsequently, Matuszek (1978) refined Ryder's equation by using more objective criteria to calculate MSY and the MEI for almost the same set of 22 lakes in the same geographical region. His equation takes the form:

$$\log_{10} Y = 0.533(\log_{10} MEI) + 0.092 \qquad \text{Eq.(2)}$$

It has also been recognized for some time that fish yields from lakes and reservoirs vary inversely with the latitude at which the lakes are located (Henderson et al.1973). Yields from temperate zone lakes tend to be smaller than those from tropical lakes, while those from subarctic lakes are smaller still. This phenomenon is probably related to differences in incident solar energy at the different latitudes. Recent work by Colby and Nepszy (1981) and Schlesinger and Regier (1982) lends support and refinement to this concept. Colby and Nepszy found that growth of walleye, a species distributed over a wide range of latitude in North America, was positively correlated with mean degree-days above 5°C. Schlesinger and Regier showed that when data from tropical and temperate zone lakes were combined in a single set, there was a significant positive correlation between yield of all species taken and the long-term mean annual air temperature in the vicinity of the lake, which they termed TEMP in their analyses.

In his original report, Ryder (1964, page 10) recognized that fish yields from some lakes, which were not yet fished intensively, might fall below the regression line represented by Equation (1). Other authors have shown that sport fishing yields are closely correlated with angling effort. Jenkins and Morais (1971) reported that angler-hours of effort accounted for 77% of the variability in sport fishing yields from 103 United States reservoirs greater than 200 ha in area. McCombie (1983) found that angler effort alone explained about 68% of the variability in sport fishing yields from 48 Ontario lakes and one lake in northern Minnesota, while 74% of the variability was explained by a combination of effort and the MEI.

It has also been suggested that fish yields may be inversely correlated with lake area (Jenkins and Morais 1971; Carlander 1977; McCombie 1983). There is a distinct possibility, however, that this is a spurious correlation, since yield is the total catch or harvest from the lake divided by area, and area occurs in both the dependent and independent variable (Youngs and Heimbuch 1982).

McCombie (1983), in dealing with the problem of relating the yield which anglers are actually taking from a lake with the potential or maximum sustainable yield estimated for that lake from Ryder's MEI model, discussed the need for corroborative evidence to show that values derived from this model do indeed approximate community maximum sustainable yields.

The purpose of the present study is to determine the relative usefulness of the MEI, angling effort, TEMP, and lake area for predicting sport fishing yields of lake trout, walleye and smallmouth bass for a large set of lakes located mainly in Ontario, using up-to-date information on all variables.

DATA SOURCES AND METHODS

Estimates of TDS, $\bar{z}$, lake surface area, fishing effort, long-term mean annual air temperature (TEMP), and sport fishing yields were compiled for 85 Ontario lakes, six Minnesota lakes, and one lake on the Nevada-California border (Tables 1 and 2). Data for most of these lakes were drawn from sets used in the Net Productivity model of the Ontario Lakeshore Capacity Study (McCombie 1983) and the report of SPOF Working Group No. 12 (OMNR 1981). Lakes in the SPOF Working Group 12 report, for which angling effort data were not readily available, are excluded from

Table 1. Data used to calculate total dissolved solids (TDS) and the morphoedaphic index (MEI). An asterisk indicates that TDS was calculated from alkalinity.

LAKE	SAMPLE DATE (month-year)	CONDUCTIVITY (umhos.cm)	CELL TEMP. (°C)	TDS (mg/L)	MEAN DEPTH (m)	MEI (mg/L/m)
Andrusia*				202	7.9	25.57
Basswood	7-80	40	25	27	30.5	0.89
Bone	8-77	21	25	14	8.5	1.65
Balsam	-76	104	25	69	5.0	13.80
Big Wolfe*				202	8.5	23.76
Bella	8-75	35	23	24	16.2	1.48
Bernard	8-73	55	26	36	15.8	2.28
Big Hawk		30.5	17	24	16.7	1.44
Boshkung	7-75	39	25	26	23.1	1.13
Brady	5-73	41	25	27	4.5	6.00
Chiblow-Denman	8-75	23	25	15	23.9	0.63
Coli	6-71	32	20	24	2.5	9.60
Cameron	-76	115	25	77	5.8	13.28
Clearwater*				44	12.8	3.44
Cass*				202	7.6	26.58
Couchiching	6-72	210	16	171	4.1	41.71
Doe	9-72	34	20	25	5.9	4.24
Dalrymple	6-72	225	22	159	2.4	66.25
Davis	5-72	85	13	74	10.0	7.40
Drag	6-75	65	26	42	18.0	2.33
Darragh	8-77	32	25	21	14.7	1.43
Eagle (Dryden)	8-73	28	24	19	6.8	2.79
Eagle (Machar)	7-72	29	20	21	6.1	3.44
Esson	6-70	100	19.7	74	10.9	6.79
Esnagi	6-71	70	24	48	5.9	8.14
Flack	8-75	26	25	17	21.5	0.79
Four-Mile	9-75	190	22	135	8.5	15.88
Glamor	6-70	96	26	63	8.8	7.16
Gull	7-75	52	25	35	16.5	2.12
Gullrock	6-80	74	25	49	7.8	6.28
Gloucester Pool	7-68	215	21.6	154	6.9	22.32
Gowganda	6-76	42	25	28	8.1	3.46
Haliburton	7-74	44	19	33	17.4	1.90
Halls	7-75	25	25	17	28.3	0.60
Head	6-75	65	24	44	3.5	12.57
Hodson	7-73	41	24	28	4.1	6.83
Joseph	8-77	35	21	25	25.3	0.99
Jimchrist	8-75	29	25	19	8.8	2.16
Keg	6-80	71	25	47	7.1	6.62
Kirkness	6-72	32	22	23	6.2	3.71
Kashagawigamog	7-75	63	25	42	13.0	3.23
Kennisis	8-74	30	20	22	22.9	0.96
Kashe	7-75	22	25	15	4.9	3.06
Kawagama	8-75	30	20	22	21.8	1.01
Lake of Bays	8-72	31	25	21	22.3	0.94
Long	8-70	101	28	63	5.5	11.45
Little Quirke	8-75	19	25	13	13.5	0.96
Lac des Milles Lacs	6-74	31	18	24	6.8	3.53
Little (near Barrie)				200	2.0	100.00
Lower Buckhorn	-76	173	25	115	3.5	32.86
Lovesick	7-72	175	26	114	2.5	45.60

Table 1 continued on page 3.

Table 1. Data used to calculate total dissolved solids (TDS) and the morphoedaphic index (MEI). An asterisk indicates that TDS was calculated from alkalinity. (Continued from page 2.)

LAKE	SAMPLE DATE (month-year)	CONDUCTIVITY (umhos.cm)	CELL TEMP. (°C)	TDS (mg/L)	MEAN DEPTH (m)	MEI (mg/L/m)
Miskwabi	8-70	104	31	62	19.1	3.25
Mississagua	8-71	49	23	34	17.7	1.92
Mountain (Minden)	7-76	60	30	36	13.4	2.69
Mountain (Minnesota)*				52	13.4	3.88
Matchedash Bay	8-72	270	24	183	1.0	183.00
Muskoka		45	19	34	16.8	2.02
Nipissing	6-76	63	25	42	4.6	9.13
Northern Light	6-74	31	18	24	8.4	2.86
Onaman	8-69	70	17	56	2.2	25.45
Orr	9-73	238	25	159	1.2	132.50
Peninsula	7-75	41	25	27	9.0	3.00
Pevensey	8-72	30	21	22	9.1	2.42
Pickerel	7-77	30	16	24	8.6	2.79
Percy	6-70	50	22	35	10.8	3.24
Redstone	7-75	29	18	22	21.9	1.00
Rebecca	8-75	40	26	26	7.9	3.29
Rosseau	9-77	50	24.5	34	25.5	1.33
Ranger	6-80	81	25	54	2.3	23.48
Red	6-80	60	25	40	14.6	2.74
Rice	-76	200	25	133	2.6	51.15
Semiwite	8-75	28	25	19	13.7	1.39
Sturgeon (Ignace)	8-76	53	25	35	13.6	2.57
Sturgeon (Lindsay)	5-72	125	24	85	3.9	21.79
Stormer	6-72	33	24.5	22	3.3	6.67
Severn Sound				112	3.9	28.72
St. John	7-74	174	25	116	4.3	26.98
Sparrow	5-75	190	25	127	4.3	29.53
Skeleton (Kirkland L.)	7-72	70	20	52	3.1	16.77
Skeleton (Bracebridge)	8-75	35	20	26	28.9	0.90
Sveny	8-75	30	19	23	11.1	2.07
Sand	7-75	35	22	25	22.2	1.13
Three-Mile		30	29	19	3.5	5.43
Twelve-Mile	5-74	45	14	38	11.7	3.25
Temagami	9-77	56	25	37	18.2	2.03
Tahoe				62	313.0	0.20
Two Island	6-80	75	25	50	4.3	11.63
Silent	6-73	40	20.5	29	6.2	4.68
Vernon	7-75	28	25	19	12.7	1.50
Wendigo	5-76	79	25	53	9.2	5.76
West Pike*				41	8.2	5.00
Whitefish (Thunder Bay)	5-74	87	22.5	61	2.0	30.50

Table 2. Data for regression analyses to predict total yield.

LAKE	AREA	MEI (mg/L/m)	TEMP (°C)	EFFORT[1] (angler -hr/ha)	YIELD[1] (kg/ha)	LENGTH OF SEASONS		RECORD YEARS	REFERENCE
Bella	338	1.48	4.8	49.5	2.68	1S	2W	1975-77	McCombie (1983) and (pers. comm.)
Bernard	2185	2.28	4.2	7.6	1.23	4S	3W	1975-78	"
Big Hawk	389	1.44	4.5	24.4	1.92	2S		1975,76	"
Boshkung	716	1.13	4.5	59.8	2.65	4S	3W	1975-78	"
Brady	89	6.00	4.6	31.0	2.77	1S		1975	"
Dalrymple	1333	66.25	5.5	33.8	2.41	3S		1975-77	"
Davis	94	7.40	4.6	31.0	2.45	1S		1978	"
Doe	1187	4.24	5.0	38.5	3.37	4S		1975-78	"
Drag	1003	2.33	4.7	14.6	0.68	2S	2W	1975-77	"
Eagle (Machar)	991	3.44	4.2	17.9	1.41	2S		1975,76	"
Esson	240	6.79	4.7	75.5	5.94	3S	1W	1975-77	"
Four-Mile	742	15.88	5.5	14.3	1.91	4S		1975-78	"
Glamor	195	7.16	4.7	31.2	3.88	2S		1975,76	"
Gull	995	2.12	4.6	36.4	1.96	4S	3W	1975-78	"
Haliburton	998	1.90	4.4	7.9	0.62	4S		1975-78	"
Halls	540	0.60	4.5	34.5	0.71	1S	1W	1976	"
Head	919	12.57	5.4	18.7	3.15	4S		1975-78	"
Hodson	355	6.83	5.0	47.5	8.50	2S		1975,76	"
Joseph	4973	0.99	5.3	5.0	0.84	4S	3W	1975-78	"
Kashagawigamog	788	3.23	4.7	20.3	1.52	4S	2W	1975-78	"
Kashe	783	3.06	5.3	15.1	2.14	1S		1975	"
Kawagama	2819	1.01	4.4	7.2	0.87	4S	3W	1975-78	"
Kennisis	1360	0.96	4.4	25.5	2.32	4S	3W	1975-78	"
Lake of Bays	7053	0.94	4.4	2.3	0.21	4S	3W	1975-78	"
Long	88	11.45	4.7	84.3	9.06	1S		1978	"
Lovesick	257	45.60	6.1	147.3	8.61	1S		1979	"
Lower Buckhorn	1234	32.86	6.1	61.8	5.04	1S		1979	"
Miskwabi	268	3.25	4.7	84.0	11.45	4S	3W	1975-78	"
Mississagua	588	1.92	5.1	18.1	0.93	2S	1W	1975-77	"
Mountain (Minden)	319	2.69	4.6	49.1	1.74	1S	1W	1978,76	"
Muskoka	10522	2.02	5.1	1.1	0.16	3S	2W	1975-77	"
Peninsula	865	3.00	4.8	11.8	1.48	1S		1975	"
Percy	341	3.24	4.4	42.4	4.70	1S		1978	"
Pevensey	155	2.42	4.2	43.7	1.67	1S		1975	"
Pickerel	513	2.79	4.2	35.9	2.59	4S		1975-78	"
Rebecca	210	3.29	4.8	49.0	2.45	1S	1W	1975,77	"
Redstone	1193	1.00	4.4	22.9	1.54	3S	3W	1975-78	"
Rosseau	5828	1.33	5.3	2.1	0.45	4S	3W	1975-78	"
Sand	527	1.13	4.2	11.6	0.98	1S		1975	"
Silent	109	4.68	4.6	69.3	5.84	1S		1979	"
Skeleton (Bracebridge)	2155	0.90	5.1	12.5	1.34	4S	3W	1975-78	"
Sweny	135	2.07	4.2	67.0	2.68	1S	2W	1976,77	"
Three-Mile	929	5.43	5.1	32.6	3.21	2S		1975,76	"
Twelve-Mile	337	3.25	4.5	61.2	3.26	3S	3W	1975-78	"
Vernon	1443	1.50	5.4	16.4	0.53	1S		1975	"
Basswood	2707	0.89	4.9	3.5	0.55	11S		1967-72	Chevalier (pers. comm.) & Purych (pers. comm.)
Bone	124	1.65	2.7	28.9	2.08		13W	1968-80	"
Chiblow-Denman	2388	0.63	4.6	4.6	0.80	13S		1967-72 1974-80	"
Darragh	182	1.43	3.8	12.4	0.80		2W	1968,69	"
Flack	951	0.79	3.8	7.6	1.37	13S		1968-79,81	"
Jimchrist	58	2.16	3.8	12.2	1.53	12S		1968-79	"
Little Quirke	389	0.96	3.8	4.1	0.43		2W	1968,69	"
Semiwite	305	1.39	3.8	7.8	0.76	12S		1968-79	"

Table 2 continued on page 5.

[1]Effort and yield data are average values for the length of record specified. In general, these values can be considered yearly averages.

Table 2. Data for regression analyses to predict total yield (continued).

LAKE	AREA	MEI (mg/L/m)	TEMP (°C)	EFFORT[1] (angler -hr/ha)	YIELD[1] (kg/ha)	LENGTH OF SEASONS		RECORD YEARS	REFERENCE
Balsam	4680	13.80	6.0	37.2	5.56	1S		1978	Lewis (pers. comm.)
Cameron	1470	13.28	6.0	28.7	3.60	1S		1978	"
Rice	10440	51.15	6.4	91.7	21.84	1S		1979	"
Sturgeon (Lindsay)	4496	21.79	6.1	42.0	6.26	1S		1977	"
Little (near Barrie)	228	100.00	6.2	75.1	7.07	2S		1978,80	Campbell and Craig (1981b,e)
Orr	303	132.50	6.0	13.7	1.31	2S		1978,80	"
Matchedash Bay	434	183.00	6.5	51.7	4.26	2S		1978,80	"
St. John	618	26.98	5.3	12.1	2.12	2S		1978,80	"
Gullrock	6759	6.28	0.7	6.8	2.85	1S		1980	Gale (1980)
Keg	1012	6.62	0.7	5.3	2.22	1S		1980	"
Ranger	1064	23.48	0.7	2.2	0.94	1S		1980	"
Red	17690	2.74	0.7	3.4	1.40	1S		1980	"
Two Island	793	11.63	0.7	4.9	2.02	1S		1980	"
Andrusia	611	25.57	3.2	56.6	9.52	5S		1971-75	Strand (1980)
Big Wolfe	425	23.76	3.2	86.7	15.12	5S		1971-75	"
Cass	6313	26.58	3.2	28.4	6.16	5S		1971-75	"
Clearwater	537	3.44	2.9	6.7	0.25	3S		1954-56	Schumacher (1961)
Mountain (Minnesota)	845	3.88	2.9	12.2	3.40	3S		1954-56	"
West Pike	289	5.00	2.9	10.0	2.62	3S		1954-56	"
Kirkness	2923	3.71	0.1	1.1	0.47	1S		1980	Carlson (1980)
Stormer	303	6.67	0.1	7.7	3.27	1S		1980	"
Gloucester Pool	1377	22.32	5.3	28.2	2.99	2S		1977,79	Campbell and Craig (1981a,d)
Sparrow	1124	29.53	5.4	28.1	2.18	2S		1977,79	"
Sturgeon (Ignace)	21413	2.57	1.1	1.4	0.42	1S		1979	McGovern (1979)
Eagle (Dryden)	27692	2.79	1.6	5.5	1.73	1S	1W	1979	Charles (1979)
Northern Light	6870	2.86	2.6	2.0	0.63	2S		1973,74	Maa (1974)
Lac de Milles Lacs	24000	3.53	0.6	12.3	4.82	5S	5W	1971-75	Elsey and Thompson (1977)
Coli	2125	9.60	0.4	5.0	1.85	1S		1980	Carlson and Malinsky (1980)
Onaman	11488	25.45	0.1	1.4	0.98	1S		1980	Walroth (pers. comm.)
Whitefish (Thunder Bay)	3015	30.50	2.8	25.7	8.46	1S		1976	Goyan, Townson, and Hamilton (1976)
Gowganda	1047	3.46	2.9	18.5	3.66	1S		1978	LaCarte (1978a)
Skeleton Kirkland Lake)	357	16.77	2.9	7.5	0.78	1S		1978	LaCarte (1978b)
Temagami	21594	2.03	3.7	4.1	0.41	3S	3W	1971,75 1978	Duckworth (1979) Koski (1976a,b; 1978)
Wendigo	419	5.76	1.9	15.5	3.20	1S		1978	LaCarte and Charles (1979)

Table 2 continued on page 6.

[1]Effort and yield data are average values for the length of record specified. In general, these values can be considered yearly averages.

Table 2. Data for regression analyses to predict total yield (continued).

LAKE	AREA	MEI (mg/L/m)	TEMP (°C)	EFFORT[1] (angler -hr/ha)	YIELD[1] (kg/ha)	LENGTH OF SEASONS	RECORD YEARS	REFERENCE
Nipissing	85500	9.13	4.2	10.6	2.70	2S	1972,73	Anthony and Jorgensen (1977)
Esnagi	4362	8.14	1.2	8.3	3.47	1S	1972	Young (1972)
Severn Sound	13052	28.72	6.1	33.0	4.65	5S	1975-79	McNeil (pers. comm.)
Couchiching	4869	41.71	6.0	11.0	1.28	3S	1978-80	Campbell and Craig (1981c,d,e)
Tahoe	49900	0.20	5.7	2.7	0.32	3S 3W	1961-63	Cordone and Franz (1966)

[1]Effort and yield data are average values for the length of record specified. In general, these values can be considered yearly averages.

our subset.

For most lakes, TDS was calculated from conductivity using the formula

$$TDS = \frac{\text{measured conductivity}}{1 + 0.02\ (\text{cell temperature} - 25)} \times 0.666 \qquad \text{Eq.(3)}$$

where TDS is stated in mg/L, conductivity in umhos.cm, and cell temperature in °C. Conductivity data (Table 1) were obtained from the files of the Aquatic Habitat Inventory Section, Ontario Ministry of Natural Resources, Whitney Block, Toronto. When more than one conductivity value was available for a particular lake, a representative value was chosen by imposing the following criteria:

1. Only conductivity values measured within 2 m of the surface were considered.
2. Of those values meeting criterion #1, values measured closest to the time when yield was estimated were considered.
3. Of those values meeting criteria #1 and #2, the lowest conductivity measurement was chosen.

When conductivity data were not available, TDS was calculated from alkalinity using Ryder's (1964) formula.

Surface areas and mean depths were obtained from Aquatic Habitat Inventory files or from individual creel census reports (Tables 1 and 2).

The long-term mean annual air temperature (TEMP) in the vicinity of each lake was derived from Wernstedt (1972) or from Environment Canada (1975). Although the ecological relevance of TEMP to fish growth is somewhat obscure, close correlations between mean values of air and surface water temperature (McCombie 1959; Brylinsky 1980) suggest that TEMP is a reasonable climatic index. The index "mean annual solar radiation" was not used because 1) freshwater primary production is more closely correlated with TEMP than with visible incident radiation (Brylinsky 1980), and 2) Canadian tables of solar radiation (Phillips and Aston 1980) provide data on too few Ontario locations to estimate an accurate value of mean annual solar radiation for most lakes.

Effort and yield data for the fisheries in this study are listed in Tables 2 and 3. In this report, angler-hours and rod-hours of effort are considered to be equivalent, as suggested in most of the creel census reports examined. There may be some difference, however, in winter fisheries where more than one line per angler is permitted, or in summer fisheries if all boat occupants are counted as anglers, regardless of whether they actually have rods. For instance, Duckworth (1979) found that effort expressed in rod-hours was 12% less than angler-hours for Lake Temagami during the summer of 1978.

Simple linear and step-wise multiple regression programs (Biomedical Computer Programs, P2R and P9R) were used to derive the best equations for predicting total sport fishing yield and individual yields of lake trout, walleye, and smallmouth bass. The fitting of species yield-effort equations was hampered by our inability to partition effort in multi-species fisheries. To deal with the problem, we assumed for practical purposes that 1) the yield of a preferred species would comprise more than 50% of total yield, and 2) total effort could be attributed to the preferred species. Nevertheless, we recognize that in a multi-species fishery this approach probably overestimates true species-specific effort.

With the exception of TEMP, all input data were converted to base 10 logarithms. The range of TEMP was too small to justify log transformation.

Table 3. Partitioned yield data for species-specific regression analyses. See Table 2 for associated effort and TEMP data.

LAKE	YIELD (kg/ha)		
	LAKE TROUT	WALLEYE	SMALLMOUTH BASS
Joseph	0.61		
Kawagama	0.56		
Rosseau	0.29		
Skeleton (Bracebridge)	1.03		
Boshkung	1.96		
Gull	1.80		
Kennisis	2.18		
Miskwabi	7.39		
Redstone	1.51		
Little Quirke	0.43		
Chiblow-Denman	0.70		
Darragh	0.80		
Flack	1.37		
Semiwite	0.76		
Basswood	0.34		
Bone	2.08		
Jimchrist	1.53		
Sturgeon (Ignace)	0.30		
Temagami	0.23		
Tahoe	0.27		
Clearwater	0.25		
Mountain (Minnesota)	3.40		
West Pike	2.62		
Three-Mile		2.17	
Lovesick		5.80	
Lower Buckhorn		3.49	
Red		0.77	
Stormer		2.21	
Lac des Milles Lacs		3.04	
Coli		1.18	
Onaman		0.84	
Sturgeon (Lindsay)		4.40	
Bernard			0.66
Doe			2.61
Eagle (Machar)			0.97
Kashe			1.56
Peninsula			1.35
Brady			1.39
Davis			1.91
Glamor			3.36
Percy			4.19

RESULTS

Angling effort proved to be the best variable for predicting both the total and species yields of sport fish from the 94 lakes in this study (Table 4).

TOTAL (MULTI-SPECIES) YIELD

As expected from previous studies, yield was positively correlated with both effort (Equation 4, Figure 1) and the MEI (Equation 5, Figure 2). In simple linear regressions, effort accounted for 61% of the variability in sport fishing yield, while the MEI explained 32%. Lake area alone accounted for about 7% of the variability in total sport fishing yield, and the slope of the line (Equation 6) was negative. The climatic variable TEMP explained only 2% of the variability (Equation 7), and the slope of the line did not differ significantly from zero ($P>0.05$).

Another very significant feature of Equation 4 and Figure 1 is that the slope of this line is

Table 4. Regression equations for predicting sport fishing yield.[1] All logarithms are to the base 10.

	EQUATION	n	r^2	PARTITIONED r^2 VALUES				
				E	MEI	MEI^2	A	TEMP
TOTAL YIELD:								
Eq.(4)	$\log Y = 0.668(\log E) - 0.507$	92	0.611	0.611				
Eq.(5)	$\log Y = 0.408(\log \text{MEI}) + 0.009$	92	0.320		0.320			
Eq.(6)	$\log Y = -0.169(\log A) + 0.806$	92	0.072				0.072	
Eq.(7)	$\log Y = 0.036(\text{TEMP}) + 0.148$	92	0.019					0.019
Eq.(8)	$\log Y = 0.745(\log \text{MEI}) - 0.203(\log \text{MEI})^2 - 0.058$	92	0.361		0.320	0.041		
Eq.(9)	$\log Y = 0.570(\log E) + 0.246(\log \text{MEI}) - 0.560$	92	0.714	0.611	0.103			
Eq.(10)	$\log Y = 0.564(\log E) + 0.548(\log \text{MEI}) - 0.181(\log \text{MEI})^2 - 0.614$	92	0.748	0.611	0.103	0.034		
SPECIES YIELD:								
Eq.(11)	log lake trout $Y = 0.770(\log E) - 0.792$	23	0.720	0.720				
Eq.(12)	log smallmouth bass $Y = 0.834(\log E) - 0.884$	9	0.700	0.700				
Eq.(13)	log walleye $Y = 0.436(\log E) - 0.174$	9	0.843	0.843				
Eq.(14)	log walleye $Y = 0.081(\text{TEMP}) + 0.106$	9	0.562					0.562

[1] Y = yield in kg/ha/yr

E = effort in angler-hours/ha/yr

MEI = morphoedaphic index = TDS/$\overline{z}$ in mg/L/m

TEMP = long-term mean annual air temperature in °C

A = lake surface area in ha

less than unity. This means that, on an arithmetic plot, it would tend to flatten at higher levels of effort. In other words, the slope of the arithmetic line, which represents the catch per unit effort (kg/ha/yr)/(angler-hr/ha/yr), diminishes as effort increases, suggesting that as effort increases the population of fish becomes significantly reduced and hence harder to catch. This is consistent with the observation that catch per unit effort is proportional to the size of the fish population which forms the basis of the Leslie and Delury methods for estimating population size (Ricker 1975).

It has been suggested that, since neither effort nor MEI can actually be measured without error, it would be more appropriate to use the geometric mean regression than least squares to fit the lines in Figure 1 and Figure 2 (Ricker 1975). Nevertheless, while this method would probably give a somewhat better fit for the individual relations yield on effort and yield on MEI, it does not appear to lend itself to the multiple regression approach taken in this report. Hence, it would not allow us to compare the relative contributions of effort, MEI, TEMP and lake area.

Multiple regressions improved the correlations. Fitting a second order polynomial by regressing $\log_{10}Y$ on $\log_{10}$MEI and $(\log_{10}\text{MEI})^2$ explained 36% of the variability in yield, while a regression of $\log_{10}Y$ on $\log_{10}$MEI, $(\log_{10}\text{MEI})^2$, and $\log_{10}E$ accounted for 75% (Equations 8 and 10).

When step-wise multiple regression analyses were performed, with the variability due to effort and the MEI taken into account first, lake area was eliminated as a significant predictor of yield, while TEMP proved to be a significant *negative* correlate with yield, accounting for an additional 8% of yield variability. A possible explanation for this change in slope is that many of the study lakes support a lake trout fishery, and it is conceivable that increasing air (and water) temperature might limit lake trout habitat and production. Hence, one might expect to get a positive correlation between yield and TEMP for lakes where the fisheries depend primarily on species other than lake trout. To test this hypothesis, 36 lakes in which the lake trout yield is >25% of total yield (by weight) were deleted from the data set, and the step-wise

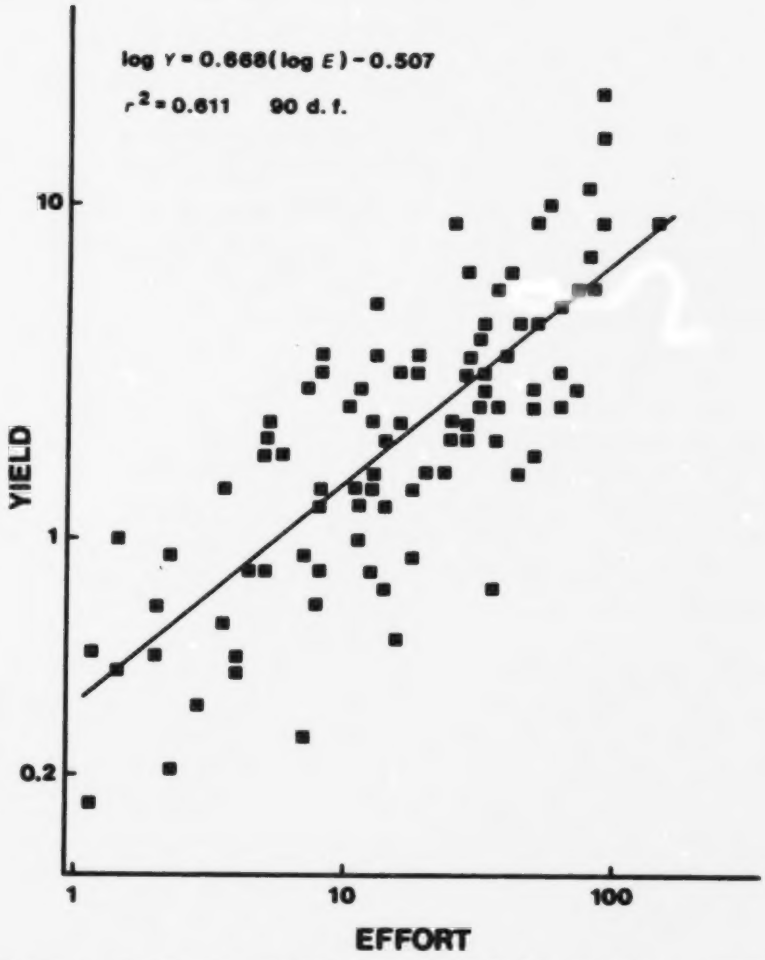

Figure 1. Total sport fishing yield (kg/ha/yr) in relation to average fishing effort (angler-hour/ha).

regression program was rerun. TEMP was again a significant variable following effort and the MEI, and again the slope was negative. Therefore, the hypothesis is not supported.

INDIVIDUAL SPECIES YIELDS

Effort accounted for 72%, 84% and 70%, respectively, of the variability in yields of lake trout *(Salvelinus namaycush)*, walleye *(Stizostedion vitreum)*, and smallmouth bass *(Micropterus dolomieui)* (Equations 11 to 13, Table 4). TEMP was also a significant positive correlate of walleye yield (Equation 14). The MEI was not a significant predictor of individual species yields, even after the variability in yield associated with differences in effort was accounted for.

CONCLUSIONS

EFFORT, THE MEI, AND FISH YIELD

When the level of exploitation of a fish community is uncertain, relative to the level that would produce MSY, then angling effort clearly is the most useful predictor of both total yield and individual species yields. The present study also confirms the observation (McCombie 1983) that angling effort and the MEI in combination account for a substantial percentage of the variability in sport fishing yields from Ontario lakes. The combined effect of these factors is described by Equation 10 (Table 4), and is illustrated by the 3-dimensional diagram in Figure 3. Bearing in mind that all scales of

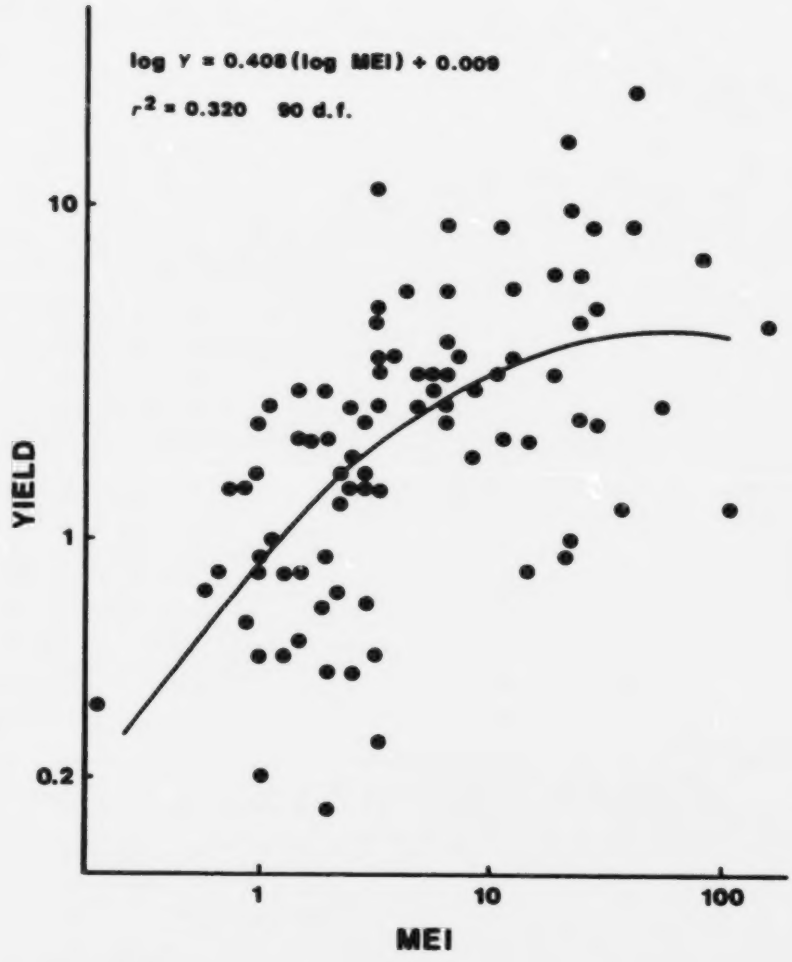

Figure 2. Total sport fishing yield (kg/ha/yr) in relation to the morpho-edaphic index (mg/L/m).

the diagram are logarithmic, and the slope of the yield-effort line (Equation 4) is less than 1.0, it is evident that yield approaches a plateau at higher levels of effort. At the same time, yield rises to a peak as the MEI approaches the middle of the range, and declines at higher MEI values.

CLIMATE AND FISH YIELD

Studies by Ryder et al. (1974), Colby and Nepszy (1981), and Schlesinger and Regier (1982) give ample evidence that growth and yield of fish from lakes increases from northern to southern latitudes, owing in part to increasing insolation. Therefore, the statistically insignificant correlation between yield and TEMP (Equation 7) suggests that the long-term mean air temperature in the vicinity of a lake may not be a sensitive enough measure of insolation to distinguish differences in fish yields over a more restricted range of latitude. It is interesting to note that Matuszek (1978) did not obtain a significant correlation between yield and degree-days above 5°C for his set of commercially-fished lakes.

LAKE SURFACE AREA AND FISH YIELD

The failure to distinguish between the harvest of fish and the yield (e.g. Jenkins 1982; Youngs and Heimbuch 1982) can lead to confusion. Strictly speaking, harvest is the total weight (or number) of fish removed from a body of water in a year or season. Yield is the total weight (or number) removed in a year or season expressed on a per unit area basis; that is, the harvest divided by the area of the lake. Hence, if one regresses yield (harvest/area) on area, the area is common to both the dependent and independent variables, and there is obviously a danger of a spurious correlation. That such a correlation

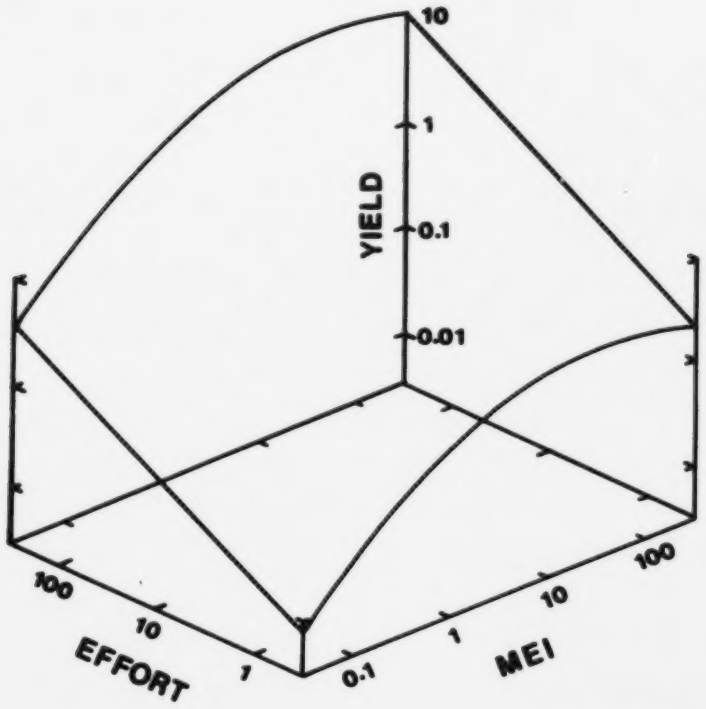

Figure 3. Schematic presentation of Equation (10), which shows the combined effect of angling effort and the MEI on sport fishing yields. Effort is in angler-hours/ha/yr, MEI in mg/L/m, and yield in kg/ha/yr.

was not picked up in our step-wise regression analysis may have been due, in part, to the over-riding effects of effort and the MEI, and partly to peculiarities of this data set which we cannot identify at present.

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APPENDIX

APPENDIX A. A POSSIBLE MODIFICATION TO THE CURRENT METHOD OF CALCULATING POTENTIAL YIELD.

Currently, biologists in the Ontario Ministry of Natural Resources use Ryder's (1965) original equation (Equation 1) to calculate potential yield which is considered to approximate the MSY for a given lake. Ryder's data, however, are not as refined as Matuszek's (1978), and Ryder included data from two lakes (Otter and Mountain) which, in fact, were not intensively-fished. Even though Matuszek found that "degree-days >5.56°C" was not a significant variable for predicting yield, the latitudinal range of Ryder's and Matuszek's lakes (42-62°N) suggests that differences in climate probably have some impact on potential fish production and yield. For predicting potential yields from Ontario lakes, some "climatic control" can be gained by recalculating the yield-MEI equations using Matuszek's data for Ontario lakes only. This results in the equation:

$$\log_{10} Y = 0.53(\log_{10} MEI) + 0.157 \qquad \text{Eq.(A-1)}$$

with $r^2 = 0.674$

where yield is stated in kg/ha/yr and the MEI in mg/L/m. Compared with Equation (2), Equation (A-1) has nearly the same slope but a higher intercept, which one would expect as a result of restricting the data set to lakes within a more southerly geographical grouping. Over the MEI range of 1-100, Equation (A-1) predicts MSY values that are 12-16% higher than values predicted from Equation (2), and 3-45% higher than values predicted from Equation (1).

It is suggested that, for the time being, Equation (A-1) would provide more realistic estimates of potential yield from Ontario lakes than either Equation (2) or the traditionally-used Equation (1).

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